IT'S A SMALL WORLD: UNDERWATER SOUND TRANSMISSION FROM THE SOUTHERN INDIAN OCEAN TO THE WESTERN NORTH ATLANTIC

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1. Introduction

Sounds transmitted through the air are rarely detectable more than a few kilometres from their source. Beneath the sea, however, acoustic signals at frequencies less than a few hundred Hertz can often be detected at ranges of several thousand kilometres. In this paper we show that low-frequency acoustic signals entering the ocean near Heard Island in the southern Indian Ocean can be detected off the east coast of North America and that relatively crude modelling is sufficient to reproduce the signal levels observed, despite the long path length of approximately 17,000 km (17 Mm).

2. Experimental Details

Although the main purpose of the Heard Island Feasibility Test (HIFT) was to evaluate the concept of using travel-time variations of sound over long base lines in the ocean as a sensitive test of global warming, this topic is adequately covered elsewhere (e.g., in Ref. 1). In this initial look at the east-coast Canadian data we are primarily concerned with the measurement and modelling of signal levels. The measurements were performed using a research array of hydrophones towed behind the Defence Research Establishment Atlantic (DREA) research vessel CFAV QUEST while in transit to its home port of Halifax. The measurement sites are denoted by the solid circles in Fig. 1.

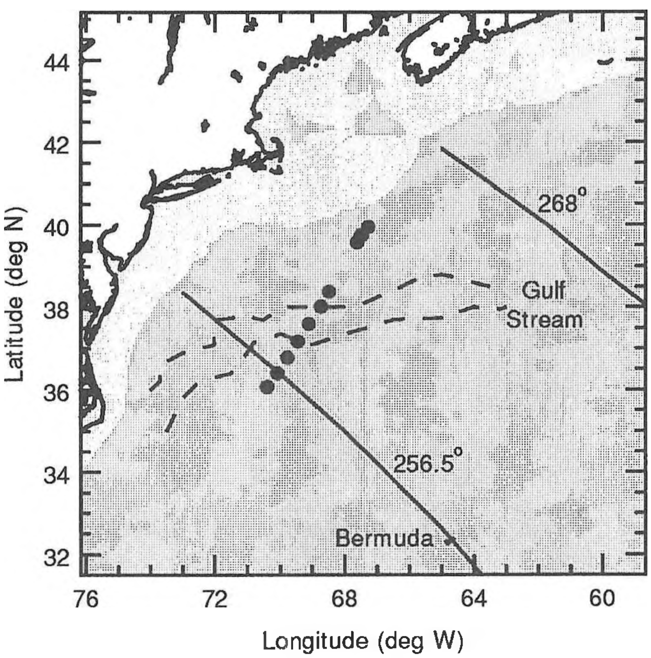

Figure 1 *Experimental area and ray paths from Heard Island.*

Figure 1 also includes the location of the Gulf Stream (dashed lines) and two ray paths from the 57 Hz source near Heard Island (the noted angles refer to emission angles at the source for these two rays). The lighter of the two grey levels denotes shallow water (less than 200 m deep). Because of shadowing by Bermuda, South America, and Africa, significant signal levels from Heard Island were expected to be found only between the two limiting rays shown in Fig. 1.

Vertical profiles of sound speed obtained from temperature measurements by QUEST are presented in Fig. 2 as a function of range along ray paths from Heard Island measured from the nominal northern boundary of the Gulf Stream. The distance of each profile from the boundary is denoted by the vertical bar near the bottom of the figure. The sound-speed scale at the top of the figure is the same for each profile, with a reference value of 1.5 km/s located directly above the range marker in each case. On crossing the Gulf Stream, the sensors moved from the warm water of the Sargasso Sea into much colder "slope" water. The dashed line shows the rapid decrease in depth of the sound speed minimum as the boundary was crossed.

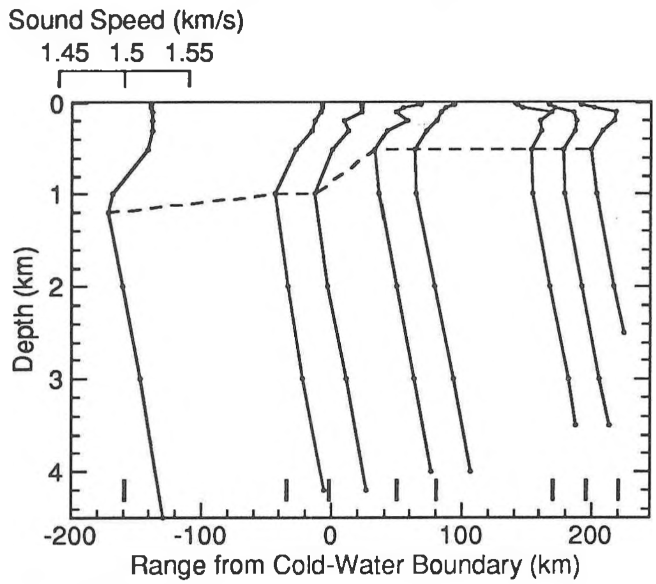

Figure 2 *Sound speeds measured near and in the Gulf Stream.*

Acoustic energy above the sound-speed minimum in Fig. 2 is refracted downward and energy below the axis is refracted upward, thereby creating a "sound channel". Sound trapped in this channel tends to follow the sound-channel minimum towards shallower depths north of the Gulf Stream. Since the sensors were being towed at depths close to 200 m, one would expect the detected signals to be stronger to the north of the Gulf Stream.

3. Transmission-Loss Modelling

The DREA normal-mode sound-transmission model PROLOS[2] was used to predict the strength of the 57 Hz Heard Island signal at the receiver. Since this model is "adiabatic" (i.e., no mode coupling is allowed), it works best in slowly changing environments. The environmental inputs for most of the acoustic path were obtained from bottom-contour charts and from a compendium of sound speeds[3]. More accurate environmental information was required near both ends of the track. Data on the source and on the nearby environment were supplied by Dzieciuch[4]. Environmental data at the receiver ranges were collected by QUEST. Model estimates of transmission loss (decrease in signal level at the receiver range relative to the level 1 m from the source) for receiver depths of 200 and 900 m are compared in Fig. 3. (Note the change in horizontal scale at 16.6 Mm, near the cold-water boundary of the Gulf Stream.)

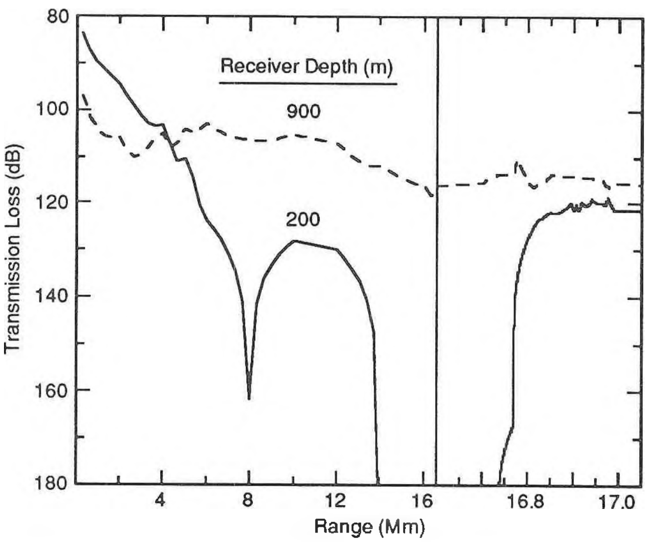

Figure 3 *PROLOS[2] model estimates of transmission loss.*

For the sensor depth of 200 m used in the experiment, the predicted transmission-loss (TL) increases rapidly at 14 Mm where the warm waters of the North Atlantic are first encountered. Between 16.7 and 16.8 Mm (near 0 km in Fig. 2), TL decreases again to levels comparable to simple "cylindrical spreading" as the receiver enters the cold water north of the Gulf Stream. The dramatic changes in TL predicted for a shallow receiver are not present at 900 m (dashed line in Fig. 3), since this depth lies much nearer the sound-channel minimum, where the signals propagating to long distances are concentrated.

The model estimates are compared with the measured TL values in Fig. 4, where the dots represent experimental data and the horizontal bars represent PROLOS-model estimates.

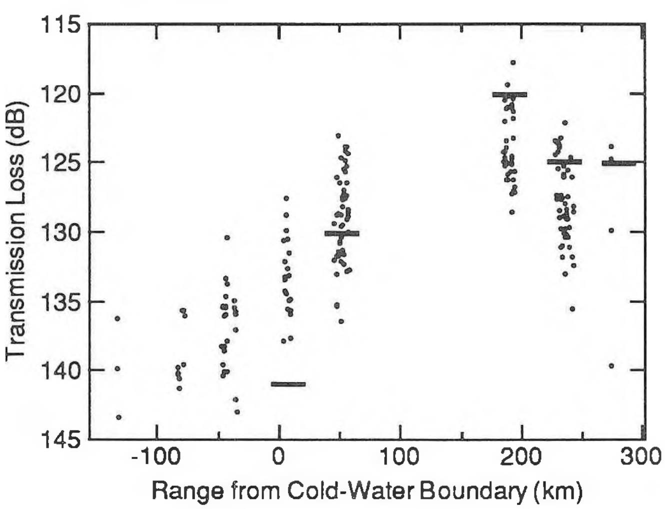

Figure 4 *Measured transmission loss.*

The maximum spectral-analysis resolution was 0.031 Hz; the resulting signal-to-noise ratio of the 57 Hz signal was typically about 10 dB. In the cold water north of the Gulf Stream (positive ranges in Fig. 4), the model and experimental mean values agree to within 3 dB. In and to the south of the Gulf Stream, the model values of TL increase rapidly, but the experimental data do not follow suit. The more gradual increase in experimental TL at negative ranges in Fig. 4 is believed to arise from the scattering of signal power from low-order modes concentrated near the sound-channel axis to higher-order modes that have significant amplitudes at the receiver depth. The scattering is attributed to interaction with the seabed, surface, and volume inhomogeneities along the sound path. PROLOS does not allow for this modal coupling, so it errs towards TL values that are too high. At still shorter ranges (not shown in Fig. 4) the 57 Hz HIFT signal was not detected, probably because of shadowing by Bermuda or South America (see Fig. 1).

4. Discussion

The good agreement between experimental and model transmission losses north of the Gulf Stream depends on the assumption of typical seabed properties at the source site. In that sense, then, we are examining the sea-bed acoustic properties near Heard Island by listening at a location southwest of Nova Scotia. Interaction with the seabed and surface in the intervening 17,000 km appears to become a significant factor only in and to the south of the Gulf Stream, where the receiver depth is ensonified only by boundary-scattered sound.

The HIFT projector source level of 200-210 dB re 1μPa@1m was at least 100 to 1000 times stronger than that normally generated by noisy merchant ships. Since ships usually control the ambient noise field near 57 Hz in the North Atlantic, and since absorption precludes long-range transmission at significantly higher frequencies, we can probably ignore contributions from the southern ocean to ambient noise in the North Atlantic.

5. Summary

The 57 Hz signals generated in the vicinity of Heard Island in January 1991 were readily detected near and in the Gulf Stream southwest of Nova Scotia at a depth near 200 m. The adiabatic normal-mode model PROLOS[2] provided good agreement with the experimental transmission loss over a 17 Mm path ending in the cold water north of the Gulf Stream. In warmer water, the model was unable to account for the relatively strong observed signal, probably because it does not include mode coupling.

Acknowledgments

Our appreciation is extended to W.H. Munk for inviting DREA to participate in the Heard Island Feasibility Test.

[1] W. H. Munk, "The Heard Island Experiment," Naval Research Reviews **43**, No. 1, 2-22 (1991).

[2] D.D. Ellis, "A two-ended shooting technique for calculating normal modes in underwater acoustic propagation," Defence Research Establishment Atlantic, Dartmouth, NS, Canada Report 85/105, Sept 1985.

[3] *World Ocean Atlas Vol. 2: Atlas of the Atlantic and Indian Oceans,* edited by S.G. Gorshkov (Pergamon, New York, 1985).

[4] M.A. Dzieciuch (private communication).